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Wavelength Division Multiplexing of a Fibre Bragg Grating Sensor using Transmit-Reflect Detection System

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Abstract Summary

Here we have performed dense wavelength division multiplexing of a single fibre Bragg grating (FBG) sensor interrogated using a transmit-reflect detection system. The FBG was used to sense an applied ultrasonic signal.

Keywords-Dense wavelength division multiplexing; fibre Bragg grating; transmit-reflect detection system.

I. INTRODUCTION

Optical fibre sensors have the potential to replace almost all traditional electrical sensors because they have many advantageous properties such as reduced size and weight, increased sensitivity, immunity to electromagnetic interference, and the ability to be multiplexed [1]. One of the most versatile optical fibre sensors currently available is the fibre Bragg grating (FBG). FBGs have been shown to measure an array of various different measurands including temperature, pressure, stress/strain, etc [2].

Whilst the diversity of fibre Bragg gratings is clearly apparent, their penetration into the industrial market has been limited, mainly because of the cost associated with the optical interrogation systems. Although utilizing FBG sensors as spectral transduction elements has the advantage of making them immune to optical power fluctuations, the spectral decoding can be slow and expensive with current, direct wavelength FBG interrogation systems on the market, costing in the region of \$50k per item, with data acquisition rates that mean they cannot be used for detection of high frequency ultrasonic signals.

The transmit-reflect detection system (TRDS) [3] is a cost effective alternative interrogation technique. The shift in wavelength is transposed into a change in optical intensity which can then easily be correlated to a change in the associated acoustic signal. Even though optical power fluctuations are reintroduced, the cost and simplicity of the detection system far outweighs the corresponding disadvantages.

In this work, we show that a FBG sensor signal can be multiplexed using dense wavelength division multiplexing (DWDM) and detected using a TRDS. Results show the frequency response and transfer function of the FBG as a proof of concept.

II. THEORY

A. Fibre Bragg Grating

A fibre Bragg grating is a small optical component written into the core of an optical fibre which consists of periodic regions of varying refractive index. When illuminated by a broadband wavelength source, the periodic regions cause the light to constructively and destructively interfere such that a narrow wavelength range, centered about a peak wavelength, is reflected and the remaining wavelengths are transmitted. Fig. 1 shows the principle of operation of a FBG.

The reflected wavelength, known as the Bragg wavelength (λ_B), is given by [4];

$$\lambda_B = 2n\Lambda, \quad (1)$$

where n is the average refractive index of the grating and Λ is the period of the grating. Any environmental factor that changes the refractive index or the grating period can be detected using a FBG. Although the FBG can be manipulated to be responsive to an array of different measurands, the change in Bragg wavelength ($\Delta\lambda_B$) is, in principle, specifically sensitive to strain (ϵ) and temperature (T).

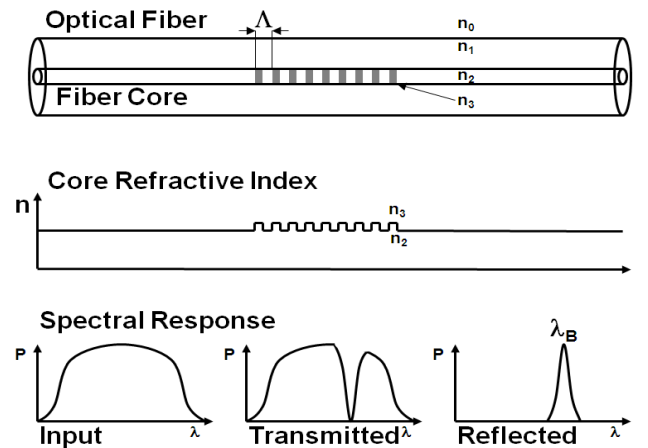


Figure 1. FBG fundamental principle of operation [3].

B. Transmit-Reflect Detection System

Intensity based detection techniques typical fall into two broad categories; edge filter detection and power detection. Edge filter detection uses a spectrally dependent filter to convert the shift in the FBG wavelength to an intensity change, whereas in power detection a spectrally dependent source converts the shift in the FBG wavelength to an intensity change.

Narrow bandwidth source based power detection uses either the reflected or the transmitted component from the FBG. However as they both occur simultaneously, they can be differentially amplified to increase the overall signal. As the strain from the acoustic field varies the Bragg wavelength, the FBGs 3dB point is also shifted. Hence, the amount of optical power reflected from the FBG will change, either positive or negative, depending on which edge of the FBG was used, and the direction of the measurand. Likewise, the amount of optical power transmitted from the FBG will change, but in the opposite direction. Fig. 2 shows the optical circuit for the TRDS, while the insert shows the principle of operation.

III. METHODOLOGY

Preliminary measurements were taken, to give the spectral response of the two 16 channel DWDM filters, the four bare FBG sensors, and the laser diode. Of the four commercial FBG sensor wavelengths available (1544, 1548, 1552, and 1556nm), the 1552nm FBG had a 3dB point closest to one of the pass band peaks in the 16 channel DWDM filter. The tunable laser was tuned to the FBG 3dB point, and the signal transmitted through the FBG was directed through the DWDM, with the output of the relevant channel (31) going to the first input on the TRDS. The signal reflected from the FBG, was then directed to the second DWDM filter via a circulator. Again the output from channel 31 was used, and connected to the second input of the TRDS. Fig. 3 shows the optical circuit used, with the principle of operation illustrated in the insert.

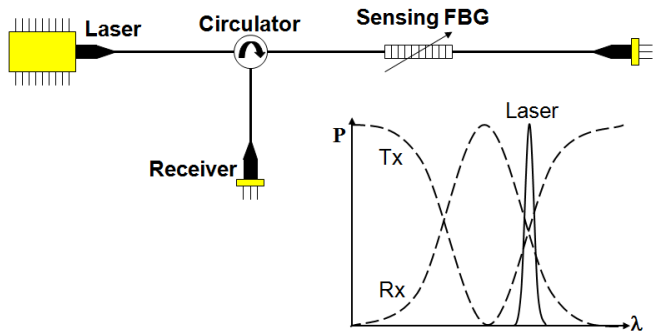


Figure 2. Optical circuit of the TRDS, with the tunable laser (TL), and the transmit (Tx) and reflect (Rx) receivers. The inset shows the spectrum of the optical components.

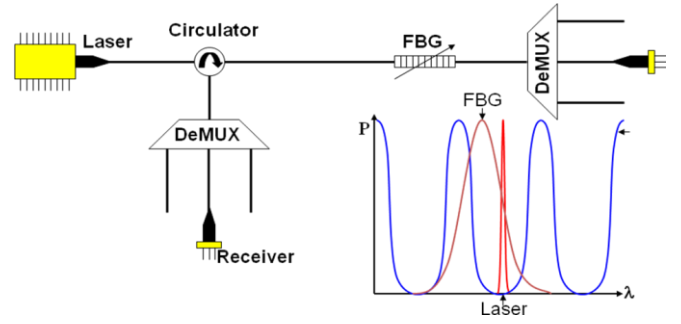


Figure 3. Optical circuit with principle of operation.

To apply the acoustic signal, the FBG was coupled to a PZT transducer, using acoustic coupling gel, and lightly held in place using tape. A signal, with varying voltage and amplitude, was then generated on the arbitrary waveform generator connected to the PZT transducer. The differential signal from the TRDS was then displayed on a DSO, connected to a PC for data acquisition. Fig. 4 shows the experimental setup to detect the acoustic signal.

IV. RESULTS

A. Locating the FBG

The first step was to determine the location of the FBG with respect to the nearest available channels from the dense wavelength division multiplexing filter. In Fig. 5 we see the relevant channels, 31 and 32, and the FBG in the middle of these. Unfortunately, all of the different FBGs sat between the 100GHz ITU channels of the 16 channel DWDM filters. Also in Fig. 5 is the corresponding laser, tuned to the FBGs upper 3dB point, which is almost equal to the first peak of channel 31.

B. Sinusoidal Output Waveform

Once the laser was tuned to the upper 3dB point of the FBG, the ultrasonic signal was applied to the FBG, at the resonant frequency of the PZT transducer, of 1.03MHz, with an input voltage of 20V peak-to-peak. The corresponding output waveform is shown in Fig. 6.

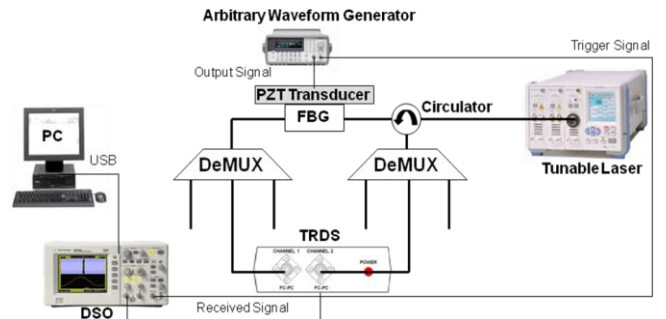


Figure 4. Experimental setup.

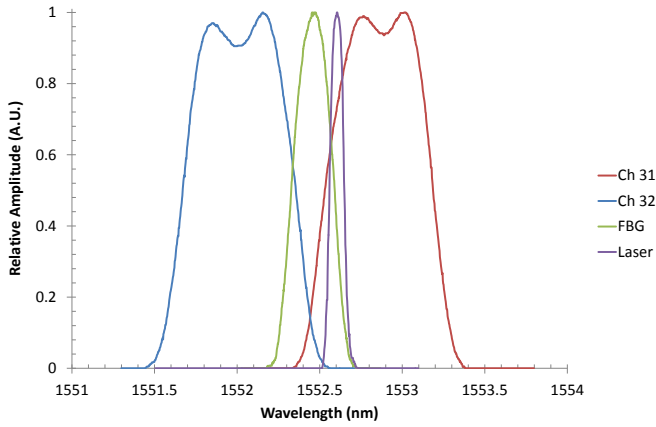


Figure 5. Spectral response of the DWDM filter channels, the FBG, and the tunable laser.

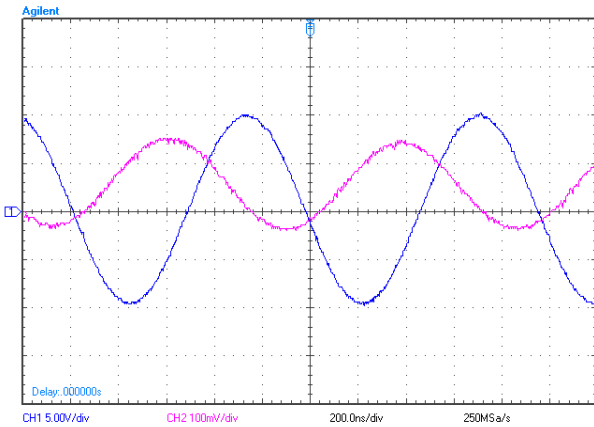


Figure 6. Output waveform (red) using the FBG receiver through the DWDM filter with the TRDS. Input (blue) frequency 1.03MHz, input voltage 10V peak-to-peak.

C. FBG Transfer Function

With the success of the TRDS to detect the applied acoustic signal using the FBG through the two DWDM filters, further basic characterization experiments were conducted. Next the transfer function was measured, by decreasing the input voltage from 20 volts peak-to-peak to 2 volt peak-to-peak, in 2 volt increments. The results are shown in Fig. 7. As expected, the transfer function is linear; the less than perfect correlation is believed to be due to thermal fluctuations over the course of measuring the data, which required several minutes, as waveforms were recorded for each value.

D. Frequency Response

Following the transfer function characterization, a quick frequency sweep was performed. Values were recorded every 0.1MHz, from 0.13MHz to 1.03MHz, with the input voltage set to 20V peak-to-peak. The frequency response is shown in Fig. 8.

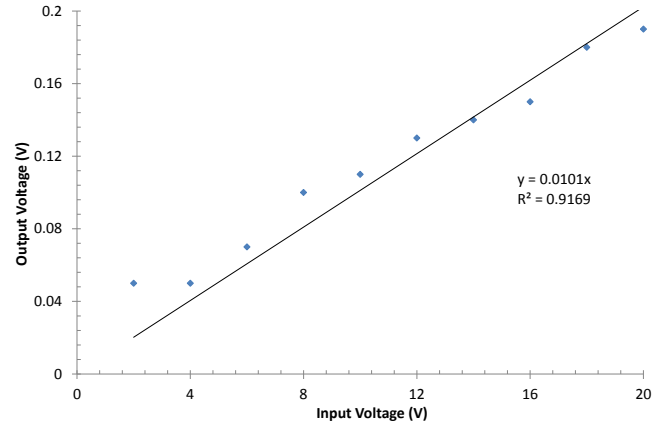


Figure 7. FBG transfer function.

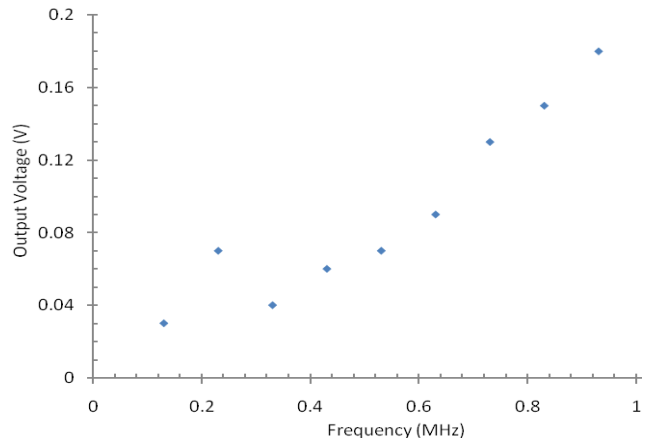


Figure 8. FBG frequency response.

CONCLUSION

In conclusion, we have demonstrated a TRDS for DWDM interrogation of a FBG sensor. The FBG was used to, successfully detect an arbitrary ultrasonic signal from a function generator. The TRDS was able to amplify the output from the DWDM by combining the transmitted and reflected signals. We have recorded a linear transfer function and frequency response curve as a proof on concept.

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